

MULTIMEDIA



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STUDENT ID NO

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MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2018/2019

EEE7256 – DEVICE PROCESSING AND FABRICATION

(Master of Electrical and Electronic Engineering)

17 OCTOBER 2018
10.00 a.m. - 1.00 p.m.
(3 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 7 pages with 3 Questions only.
2. Attempt **ALL** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

QUESTION 1

- (a) Float-zone (Fz) technique can be used to grow silicon (Si) crystal that has lower contamination than that normally obtained from the Czochralski (Cz) technique. With schematic aids, describe the operation principle of the Fz technique in the growth of Si crystals. [2+5 marks]
- (b) After removal from the crystal grower, the Si crystal typically goes through a series of steps that finally result in the finished Si wafer for device processing. Briefly describe those steps involved. [9 marks]
- (c) A certain amount of Boron (B) dopant is mixed into the Si melt, which is contained in a crucible of a Cz crystal grower. A boule of single crystal Si is pulled from the melt, which is sliced into thin sheet of wafers after the pulling process. The wafer taken from the top of the Si boule has a doping concentration of $5 \times 10^{16} \text{ cm}^{-3}$. The segregation coefficient (k) for B is given as 0.8. Determine the doping concentration of the wafer taken from the position corresponding to 60% of the initial charge solidified. Identify the conductivity type of these doped wafers. [3 marks]
- (d) Describe laminar-flow clean room concept which was developed for early adoption in microelectronic industries. [2 marks]
- (e) Once a wafer has been successfully completed to the point that the product die can be electrically tested, the figure of interest is the design yield, or die yield. List out two basic die yield components and briefly distinguish these two die yield components. [4 marks]

Continued

QUESTION 2

- (a) Thermal diffusion and ion implantation are two mainstream techniques to introduce impurities into intrinsic semiconductors to create extrinsic semiconductors.
- (i) Describe the distinctive features of the thermal diffusion and the ion implantation techniques, respectively, in the doping process. [7 marks]
- (ii) In a doping process, phosphorus (P) is implanted in silicon (Si) wafer in order to create an implanted n-doped region within the Si wafer. The projected range of the implanted profile is 3000 Å. Given the standard deviation of the projected range as 600 Å. Determine the depth of peak of the implanted profile, and the peak concentration of the P dopants for an implantation dose of 10^{12} cm^{-2} adopted in the implantation doping process. [3 marks]
- (iii) A pre-deposition thermal diffusion process using P as dopant source is performed on a p-type Si wafer at 1000 °C for 30 minutes in order to create a p-n junction. The P concentration supplied at the wafer surface is $1 \times 10^{20} \text{ cm}^{-3}$ and the background doping concentration of the p-type wafer is $1 \times 10^{16} \text{ cm}^{-3}$. Given the diffusion coefficient for the P at 1000 °C is $1.5 \times 10^{-15} \text{ cm}^2\text{s}^{-1}$, find the junction depth of the p-type Si wafer after the pre-deposition thermal diffusion process. [5 marks]
- (b) Thin films can be classified into five groups of film layers; thermal oxides, dielectric layers, epitaxial layers, polycrystalline silicon and metal films.
- (i) Briefly describe what is epitaxial growth in film deposition. [2 marks]
- (ii) Distinguish between a homoepitaxy growth and a heteroepitaxy growth in film deposition. Give one example of the homoepitaxy and the heteroepitaxy growth processes, respectively. [6 marks]
- (iii) Chemical vapor deposition (CVD) is one of the common techniques for epitaxial growth. With the aid of a schematic diagram, describe the physical mechanisms of the chemical vapor deposition (CVD) process. [3+5 marks]

Continued

QUESTION 2

(c) Photoresist is a light-sensitive material used in photolithographic process for the patterning of the microstructures.

- (i) Compliment the following performance factors of the positive and negative photoresists, respectively, given in Table 2(c) [8 marks]

Table 2(c)

Performance factors	Negative	Positive
Resolution		
Etch resistance		
Thermal stability		
Exposure speed		

- (ii) Describe the arrangement of the mask with respect to the wafer during the exposure and alignment processes, for the contact and proximity printers, respectively. [4 marks]
- (iii) Given a proximity photolithography exposure system with an exposure wavelength of 265 nm and resist constant of 0.8. Estimate the gap required between the mask and the Si wafer for this proximity exposure system to achieve 500 nm resolution. [2 marks]
- (d) Etching is the process of removal for any unwanted layers from the wafer surface, through the wet chemical (wet etching) or dry physical (dry etching) processes. Describe the physical mechanisms, any four advantages and disadvantages of the wet etching process, respectively. [11 marks]
- (e) Figure 2(e) shows the photolithography process for patterning silicon dioxide (SiO_2) on Si wafer. Sketch the final SiO_2 structure on Si wafer, following patterning process using positive (+PR) and negative (-PR) photoresists, respectively. [4 marks]

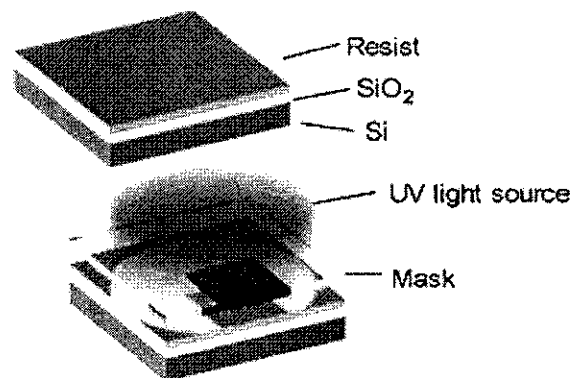


Figure 2(e): Photolithography process for patterning SiO_2 on Si wafer.

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QUESTION 3

The cross-sectional view of a complementary metal-oxide-semiconductor (CMOS) inverter on a p-type silicon (Si) substrate is given in Figure 3. The CMOS inverter can be fabricated using either n-well process or p-well process. Design a n-well fabrication process for the CMOS inverter. Illustrate each processing step, starting from the p-type Si substrate. [15 marks]

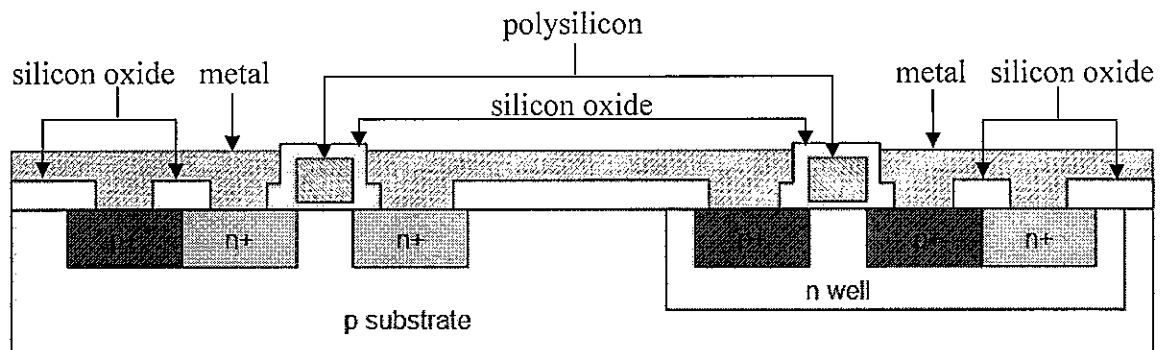


Figure 3: Schematic cross-section of a CMOS inverter.

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Values of the error function $\text{erf}(t) = \frac{2}{\sqrt{\pi}} \int_0^t e^{-a^2} da$

t	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.0113	0.0226	0.0338	0.0451	0.0564	0.0676	0.0789	0.0901	0.1013
0.1	0.1125	0.1236	0.1348	0.1459	0.1569	0.1680	0.1790	0.1900	0.2009	0.2118
0.2	0.2227	0.2335	0.2443	0.2550	0.2657	0.2763	0.2869	0.2974	0.3079	0.3183
0.3	0.3286	0.3389	0.3494	0.3593	0.3694	0.3794	0.3893	0.3992	0.4090	0.4187
0.4	0.4284	0.4380	0.4475	0.4569	0.4662	0.4755	0.4847	0.4937	0.5027	0.5117
0.5	0.5205	0.5292	0.5379	0.5465	0.5549	0.5633	0.5716	0.5798	0.5879	0.5959
0.6	0.6039	0.6117	0.6194	0.6270	0.6346	0.6420	0.6494	0.6566	0.6638	0.6708
0.7	0.6778	0.6847	0.6914	0.6981	0.7047	0.7112	0.7175	0.7238	0.7300	0.7361
0.8	0.7421	0.7480	0.7538	0.7595	0.7651	0.7707	0.7761	0.7814	0.7867	0.7918
0.9	0.7969	0.8019	0.8068	0.8116	0.8163	0.8209	0.8254	0.8299	0.8342	0.8385
1.0	0.8472	0.8468	0.8508	0.8548	0.8586	0.8624	0.8661	0.8698	0.8733	0.8768
1.1	0.8802	0.8835	0.8868	0.8900	0.8931	0.8961	0.8991	0.9020	0.9048	0.9076
1.2	0.9103	0.9130	0.9155	0.9181	0.9205	0.9229	0.9252	0.9275	0.9297	0.9319
1.3	0.9340	0.9361	0.9381	0.9400	0.9419	0.9438	0.9456	0.9473	0.9490	0.9507
1.4	0.9523	0.9539	0.9554	0.9569	0.9583	0.9597	0.9611	0.9624	0.9637	0.9649
1.5	0.9661	0.9673	0.9684	0.9695	0.9706	0.9716	0.9726	0.9736	0.9746	0.9755
1.6	0.9764	0.9772	0.9780	0.9789	0.9796	0.9804	0.9811	0.9818	0.9825	0.9832
1.7	0.9838	0.9844	0.9850	0.9856	0.9861	0.9867	0.9872	0.9877	0.9882	0.9886
1.8	0.9891	0.9895	0.9899	0.9904	0.9907	0.9911	0.9915	0.9918	0.9922	0.9925
1.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
2.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
2.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
2.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
2.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
2.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
2.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
2.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
2.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99998	.99998	.99998	.99998	.99998	.99998	.99999	.99999	.99999

for $t > 3$ $\text{erf}(t) \approx 1 - \frac{1}{\sqrt{\pi} t} \exp(-t^2)$

$\text{erfc}(t) = 1 - \text{erf}(t)$

Continued

APPENDIX**Physical Constants:**Avogadro number, $N_{\text{avo}} = 6.02217 \times 10^{23} \text{ mol}^{-1}$ Boltzmann constant, $k = 1.380622 \times 10^{-23} \text{ J K}^{-1} = 8.61712 \times 10^{-5} \text{ eV K}^{-1}$ Electronic charge, $e = 1.60219 \times 10^{-19} \text{ C}$ Electron rest mass, $m_0 = 9.10956 \times 10^{-31} \text{ kg}$ Electron volt, $1 \text{ eV} = 1.60219 \times 10^{-19} \text{ J}$ Si yield strength = $2 \times 10^7 \text{ dynes cm} = 7 \text{ GPa}$ Latent heat of fusion for Si, $L = 340 \text{ cal g}^{-1}$ Thermal conductivity of Si, $k = 0.21 \text{ W cm}^{-1} \text{ }^\circ\text{C}^{-1}$ Amount of heat of 1 calorie = 4.14 J Density of bulk Si = 2.33 g cm^{-3} Density of molten Si = 2.53 g cm^{-3} Electric current of $1 \text{ A} = 1 \text{ Cs}^{-1}$ Atomic mass unit of $1 \text{ amu} = 1.66053 \times 10^{-27} \text{ kg}$ Magnetic flux density of $1 \text{ T} = 1 \text{ Wb m}^{-2} = 10^4 \text{ G}$ Angstrom unit of $1 \text{ \AA} = 1 \times 10^{-10} \text{ m} = 0.1 \text{ nm} = 1 \times 10^{-4} \text{ }\mu\text{m}$ Permittivity of free space = $8.85 \times 10^{-14} \text{ F cm}^{-1}$ Pressure of $1 \text{ Torr} = 133.32237 \text{ Pa}$ **Formulas:**

$C(x,t) = C_s \operatorname{erfc} \left[\frac{x}{2\sqrt{Dt}} \right]$	$N(x) = \frac{Q_0}{\sqrt{2\pi\Delta R_p}} e^{\left[-\frac{1}{2} \left(\frac{x-R_p}{\Delta R_p} \right)^2 \right]}$
$C(x) = \frac{Q}{\sqrt{\pi Dt}} e^{-\left(\frac{x}{2\sqrt{Dt}} \right)^2}$	$N(R_p) = \frac{Q_0}{\sqrt{2\pi\Delta R_p}} = N_p$
$x_j = 2\sqrt{Dt} \ln(N_0/N_B)$	$C_s = \frac{Q}{\sqrt{\pi Dt}}$
$x_j = 2\sqrt{Dt} \operatorname{erfc}^{-1}(N_B/N_0)$	$Q = 2C_s \sqrt{\frac{Dt}{\pi}}$
$k_0 = \frac{C_s}{C_i}$	$Q = \sqrt{2\pi} N_p \Delta R_p$
$W_{\min} = \sqrt{k\lambda g}$	$C = k C_0 (1-x)^{k-1}$
$W_{\min} = k \{\lambda / NA\}$	

End of paper